University of Technology, Sydney

AN ADAPTIVE TUNABLE VIBRATION ABSORBER USING MAGNETORHEOLOGICAL ELASTOMERS FOR VIBRATION CONTROL OF VEHICLE POWERTRAINS

By

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Submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

Faculty of Engineering and Information Technology

June, 2011

CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signed

Nga Hoang

Acknowledgments

I would like to thank my principal supervisor Professor Nong Zhang for his supervision and support during my thesis. His helpful advice is invaluable for me not only in the PhD course but also in my further studies.

I would also like to thank my co-supervisor Dr. Haiping Du for his guidance. Under his supervision my research skills have improved significantly. His careful review has also helped me a lot during this work. It is my pleasure to work with him.

The support from Professor Weihua Li and Tongfei Tian, University of Wollongong is greatly appreciated. The author also would like to thank Professor Peter Watterson, Chris Chapman, Michael Tran and Lifu Wang for their technical support during the experimental testing stage.

A special thanks to Dr. Wade Smith and my colleagues Paul Walker, Jin Zhang, Salisa Abdul Rahman, Yoo Shin Kim, Jing Zhao and Robert Heal for their great friendship at the University of Technology, Sydney.

I would like to sincerely thank Vietnam's Overseas Scholarship Program (Project 322), Vietnam International Education Development, Vietnam's Ministry of Education and Training for the doctoral scholarship. Also, the financial support by the Australian Research Council (ARC LP0775445) is gratefully acknowledged.

Special thanks to my parents, sisters and brothers and other members of my family for their support and encouragement. Particularly, thanks to my son, Viet Hoang, and my little daughter, Ngan Hoang for their love.

Finally, I would like to give special thanks to my wife, Thi Yen Hoang, who has stood by me through all circumstances of ups and downs. Thank you for your understanding and support.

Sydney 9-6-2011

Nga Hoang

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Abstract

Powertrains are a crucial subsystem of vehicles and are also a source of the vibration. Because of the wide range of operating frequencies of powertrain, the likelihood of the engine working speed being in the resonance area is very high. Moreover, the resonance cannot be avoided when the engine speed passes through one or more modal powertrain frequencies in the transient stage. An example of the transient stage is that the engine accelerates from idle to top working speeds. Consequently, powertrains may experience a high level of vibration.

This thesis presents the development of torsional adaptive tunable vibration absorber (ATVA) using magnetorheological elastomers (MREs) for powertrain vibration control. The effectiveness of the ATVA is examined by both methods: numerical simulations and experimental testing.

The MRE is a smart material consisting of a host matrix and magnetic particles and the MRE material is promising for constructing ATVAs because its elastic moduli and damping can be controlled magnetically. Consequently, a MRE-based ATVA can work in a wide frequency range instead of a narrow bandwidth as a traditional vibration absorber does.

The principal idea of this thesis is that by tuning the MRE-based ATVA modal frequency and by choosing the ATVA location, powertrain modal frequencies can be actively shifted away from the resonant area for either steady or transient states. Numerical simulations are conducted to show the ATVA's effectiveness. In addition, the application of multiple ATVAs for dealing with multi-harmonic excitations is numerically examined. The numerical simulations are also used to facilitate the ATVA design, in which, the effect of ATVA parameters such as moment of inertia, stiffness and damping is investigated.

A MRE material is fabricated to develop an ATVA for experimental validation. With the MRE measured properties, an ATVA is designed and manufactured. Both designed and experimental results of ATVA modal frequency are in a good agreement. The ATVA can work in a frequency range from 10.75 to 16.5Hz (53% in relative change).

To validate the ATVA's effectiveness, experimental testing is conducted for a powertrain test rig at the University of Technology, Sydney. The powertrain fitted with the ATVA is experimentally investigated. The experimental results show that with the ATVA the powertrain modal frequencies can be shifted far away from the resonant area. This finding confirms that the ATVA works effectively. The torsional MRE-based ATVA is a new device for vehicle powertrain vibration reduction.

Abbreviations

ATVA	Adaptive Tuned Vibration Absorber
TVA	Tunable vibration absorber
AT	Automatic transmission
MT	Manual transmission
TC	Torque converter
ICD	Internal Crankshaft Damper
BSD	Balanceshaft Damper
DMF	Dual Mass Flywheel
ICE	Internal combustion engine
DOF	Degree of freedom
SDOF	Single degree of freedom
MDOF	Multi degrees of freedom
EOM	Equation of motion
ODE	Ordinary differential equation
SMA	Shape memory alloy
MR	Magnetorheological
MRE	Magnetorheological elastomer
MRF	Magnetorheological fluid
FFT	Fast Fourier Transformation
SSA	State-switched absorbers
UTS	University of Technology, Sydney

List of Symbols

a	constant, length
A	area, cross section area
A	system matrix
b	constant, length
B	magnetic flux density
c_A	ATVA damping coefficient
c	damping coefficient
c_{ij}	damping coefficient
C	damping matrix
d	distance, diameter
h	real part of complex eigenvalue
E	Young's modulus
F	force
G	shear modulus
$\hat{G}$	complex shear modulus
G'	storage modulus
G''	loss modulus
H	magnetic field intensity
I	electric current
i	integer
I	identity matrix
J	moment of inertia
J	inertia matrix
J_A	moment of inertia of dynamic absorber
k_i	torsional spring coefficient
k_{ij}	stiffness coefficient
K	stiffness matrix
k_A	stiffness coefficient of dynamic absorber, MRE stiffness
l, l_i	length
m	mass
n	an integer

N	number of degrees of freedom, number of turn of electric coil
Q_i	i^th generalized force
R	dissipation function, radius
R	matrix of transfer functions
R_i	inner radius
R_O	outer radius
t	time
T	torque, kinetic energy
T_i	kinetic energy of i^{th} body
V	potential energy
V_i	potential energy of i^{th} spring
x	vibration response
X	vibration amplitude, vibration complex amplitude
$\overline{X}$	vibration amplitude
W	width
z	state vector
α	angle, constant
β	angle, constant
γ	dynamic harmonic strain
ΔF	increment in F
Δl	increment in l
ε	strain
ς	damping ratio
ς_A	ATVA damping ratio
θ	angular displacement
$\boldsymbol{\theta}$	vector of angular displacement
θ_i	i^{th} angular displacement
$\boldsymbol{\Theta}$	vector amplitude of θ
λ	eigenvalue
μ	mass ratio, inertia ratio
ϕ	magnetic flux, phase angle
ω	frequency
ω_i	i^{th} natural frequency

ω_n	natural frequency
ω_d	damped frequency
Ω	excitation frequency, forcing frequency
ρ	mass density

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